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RADIATION ABSORPTION EFFECTS ON UNSTEADY MHD FLOWOF RADIATIVE AND CHEMICALLY REACTING FLUID PAST A POROUS PLATE WITH VARIABLE SUCTION AND CONCENTRATION

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ABSTRACT

This paper focuses on the effects of chemical reaction and radiation absorption, on unsteady MHD free convection fluid flow, embedded in a porous medium with time dependent suction and temperature gradient heat source, in two different cases of boundary conditions.

Case (I): $u = u_p, \quad \theta = 1+\varepsilon e^{nt}, \quad C = 1+\varepsilon e^{nt} \quad at \quad y = 0$

$$u \to 0, \quad \theta \to 0, \quad C \to 0 \quad as \quad y \to \infty$$

Case (II): $u = 1+\varepsilon e^{nt}, \quad \theta = 1+\varepsilon e^{nt}, \quad C = 1+\varepsilon e^{nt} \quad at \quad y = 0$

$$u \to 0, \quad \theta \to 0, \quad C \to 0 \quad as \quad y \to \infty$$

The parabolic partial differential equations governing the fluid flow, heat transfer and mass transfer have been solved, by using the perturbation technique. The velocity, temperature, concentration, skin friction coefficient, rate of heat transfer and rate of mass transfer at the plate are presented in graphs, and the effects of various physical parameters like Prandtl number Pr, thermal Grash of number Gr, mass Grash of number Gm, Schmidt number Sc, chemical reaction parameter Kr, magnetic field parameter M, thermal radiation parameter Nr, Radiation absorption parameter R and heat source parameter Qon the above flow quantities are analyzed and the results obtained are physically interpreted.

KEYWORDS: ***MHD, Unsteady, Chemical Reaction, Radiation Absorption & Skin-Friction***

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Original Article

INTRODUCTION

The phenomenon of mixed convection has been the object of extensive research. The importance of this phenomenon is increasing, due to its enhanced concern in science and technology, about bounce induced motions in the atmosphere, and the bodies of water and quasi solid bodies, such as earth are related to them. Convective flows in porous media have applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. The hydro magnetic convection with heat and mass transfer, in porous medium has been studied. It is due to its importance in the design of magneto hydrodynamic generators, accelerators in geophysics, the design of underground water, energy storage system, astrophysics, soil sciences and so on. On account of their importance, these flows have been studied by several authors, among them are Elbashbeshy [1],

Yih [2], Hossain and Rees [3], Mahapatra et al. [4], Srinivas and Muthuraj [5], Raju and Varma [6].

Combined heat and mass transfer problems with chemical reaction, are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In the processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one in which, electrical energy is extracted directly from a moving conducting fluid. Chamkhaet al [7], used the blotter difference method, to study the laminar free convection flow of air past a semi-infinite vertical plate, in the presence of chemical species concentration and thermal radiation effects. The effect of chemical reaction to free convective flow and mass transfer, of a viscous incompressible and electrically conducting fluid over a stretching sheet was investigated by Afify [8], in the presence of transverse magnetic field. Ibrahim and Abdullah [9] derived the analytical solution for the steady MHD mixed convection, laminar, heat and mass transfer flow, over an isothermal inclined permeable stretching sheet, immersed in a uniform porous medium in the presence of chemical reaction, thermal radiation, Dufour and Soret effects, an external transverse magnetic field and internal heating. In the study of Alam et al. [10] an analysis is carried out to investigate the effects of variable chemical reaction, thermophoresis, temperature-dependent viscosity and thermal radiation on an unsteady MHD free convective heat and mass transfer flow of a viscous, incompressible, electrically conducting fluid past an impulsively started infinite inclined porous plate. The results show that, higher order chemical reaction induces the concentration of the particles for a destructive reaction, and reduces for a generative reaction. Rashad et al. [11] considered MHD free convective heat and mass transfer of a chemically reacting fluid, from radiate stretching surface embedded in a saturated porous medium. The Uri et al. [12], studied unsteady double diffusive MHD boundary layer flow of chemically reacting fluid, over a flat permeable surface.

The study of heat generation or absorption effects, in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reaction. Due to the fast growth of electronic technology, effective cooling of electronic equipment has become warranted, and cooling of electronic equipment ranges from individual transistors to mainframe computers and from energy suppliers to telephone switchboards, and thermal diffusion effect has been utilized for isotope separation in the mixture, between gases with very light molecular weight (hydrogen and helium) and medium molecular weight. Hossain et al. [13], studied the problem of natural convection flow along a vertical wavy surface, with uniform surface temperature in the presence of heat generation/ absorption. Hady et al. [14], investigated the problem of free convection flow, along a vertical wavy surface embedded in electrically conducting fluid saturated porous media, in the presence of internal heat generation or absorption effect. Chemical reaction and radiation effects, on unsteady MHD free convective fluid flow, embedded in a porous medium with time dependent suction with the temperature gradient heat source, was studied by Seshaiah et al. [15]. Recently, Balamurugan et al. [16] analyzed the effects of chemical reaction, thermal radiation and radiation absorption on unsteady double diffusive free convection flow of Kuvshinski fluid past, a moving porous plate with heat generation, under the influence of a uniform transverse magnetic field. Das et al. [17], investigated MHD boundary layer slip flow and heat transfer of nano fluid past a vertical stretching sheet, with non-uniform heat generation/ absorption.

This paper aims at studying the effects of chemical reaction and radiation absorption, on unsteady MHD free convection fluid flow, embedded in a porous medium with time dependent suction and temperature gradient heat source, in

two different cases of boundary conditions.

Case (I): $u = u_p, \quad \theta = 1 + \varepsilon e^{nt}, \quad C = 1 + \varepsilon e^{nt} \quad at \quad y = 0$

$u \to 0, \quad \theta \to 0, \quad C \to 0 \quad as \quad y \to \infty$

Case (II): $u = 1 + \varepsilon e^{nt}, \quad \theta = 1 + \varepsilon e^{nt}, \quad C = 1 + \varepsilon e^{nt} \quad at \quad y = 0$

$u \to 0, \quad \theta \to 0, \quad C \to 0 \quad as \quad y \to \infty$

FORMULATION OF THE PROBLEM

We consider a problem of unsteady two dimensional, laminar boundary layer flow of viscous, incompressible, electrically conducting fluid, along a semi-infinite vertical plate in the presence of thermal and concentration boundary effects. A variable time-dependent suction velocity $v' = -V_0(1 + \varepsilon A e^{n't'})$ is considered normal to the flow. The plate is taken along x' - axis in vertical upward direction, against the gravitational field. y' - axis is taken normal to the flow, in the direction of applied transverse magnetic field. Further, due to semi-infinite plane surface assumption, the flow variables are the functions of y' and t' only. The following assumptions are made in the governing equations.

- The viscous dissipation is neglected.
- The Joule dissipation is neglected.
- The induced magnetic field is assumed to be negligible, as the magnetic Reynolds number of the flow is taken to be very small.

The governing equations of the problem in dimensional form are

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = -\frac{\sigma B_o^2}{\rho} u^* + \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\upsilon}{k^*} u^* \tag{2}$$

$$\frac{\partial T}{\partial t^*} + v^* \frac{\partial T}{\partial y^*} = v \frac{\partial^2 T}{\partial y^{*2}} - \frac{1}{\rho c_p} \frac{\partial q_r}{\partial y^*} + \frac{\overline{Q}}{\rho C_p} \frac{\partial}{\partial y}(T \;\; - T_\infty) + R^*(C - C_\infty) \tag{3}$$

$$\frac{\partial C}{\partial t^*} + v^* \frac{\partial C}{\partial y^*} = v \frac{\partial^2 C}{\partial y^{*2}} - k_r^{'2} C \tag{4}$$

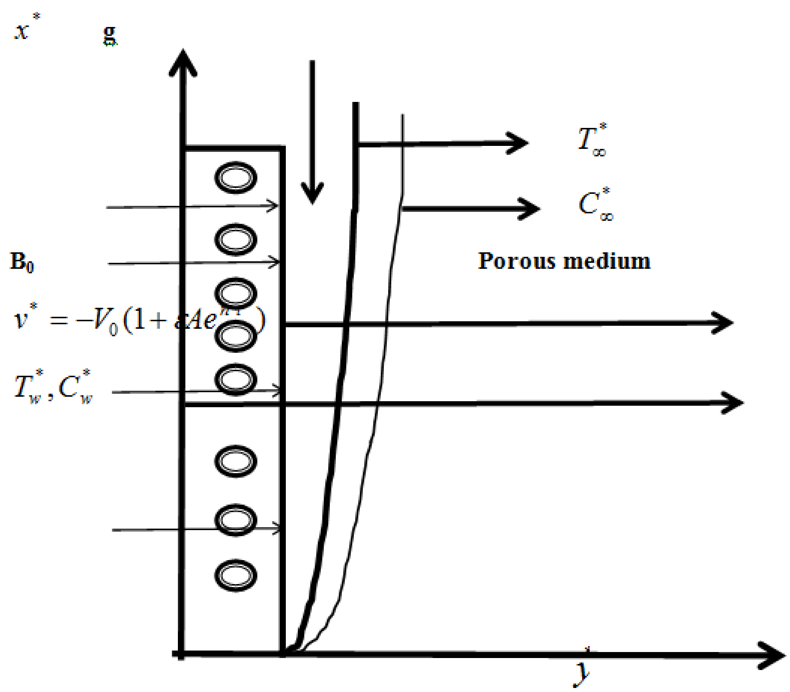

Figure 1: Physical Configuration and Coordinate System

The corresponding initial and boundary conditions are

Case (I): $u^* = u_p^*, T = T_w + \varepsilon(T_w - T_\infty)e^{n^*t^*}, C = C_w + \varepsilon(C_w - C_\infty)e^{n^*t^*} \quad at \quad y = 0$

$$u^* \to 0, \quad T^* \to T_\infty, \quad C^* \to C_\infty \quad as \quad y \to \infty \tag{5}$$

Case (II) $u = 1 + \varepsilon e^{n^*t^*}, \quad T = T_w + \varepsilon(T_w - T_\infty)e^{n^*t^*}, \quad C = C_w + \varepsilon(C_w - C_\infty)e^{n^*t^*} \quad at \ y = 0$

$$u^* \to 0, \quad T^* \to T_\infty, \quad C^* \to C_\infty \quad as \quad y \to \infty \tag{6}$$

By using Rosselant approximation, we can write the radiative flux q_r as:

$$q_r = \frac{4\sigma^*}{3k^*}\frac{\partial T^{*4}}{\partial y^*} \tag{7}$$

It is assumed that, the temperature differences within the flow are sufficiently small so that T^{*4} can be expanded in a Taylor series, about the free stream temperature T_∞^* so that, after rejecting higher order terms:

$$T^{*4} \approx 4T_\infty^{*3}T - 3T_\infty^{*4} \tag{8}$$

The equation of energy after submission of equations (7) & (8), can be written as

$$\frac{\partial T}{\partial t^*}+v^*\frac{\partial T}{\partial y^*}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^{*2}}+\frac{16\sigma^* T_\infty^3}{3\rho c_p k^*}\frac{\partial^2 T}{\partial y^{*2}}+\frac{\overline{Q}}{\rho C_p}\frac{\partial}{\partial y}(T\ -T_\infty)+R^*(C-C_\infty) \tag{9}$$

From equation (1), $v^* = -V_0(1+\varepsilon A e^{n^* t^*})$ (10)

Where, A is the suction parameter and εA << 1. Here, the minus sign indicates that, the suction is towards the plate.

The following non-dimensional parameters are introduced in the equations (2), (4) & (9) to get the dimensionless form.

$$u=\frac{u^*}{U_0},\quad y=\frac{y^* U_0}{v},\quad t=\frac{t^* U_0^2}{v},\quad n=\frac{n^* v}{U_0^2},\quad u_p=\frac{u_p^*}{U_0},\mathrm{Pr}=\frac{\rho c_p v}{k},\quad Sc=\frac{v}{D},\quad M=\frac{\sigma B_0^2 v}{\rho U_0^2},$$

$$Gr=\frac{vg\beta(T_w^*-T_\infty^*)}{U_0^3},\quad K=\frac{k^* U_0^2}{v^2},\quad \theta=\frac{T^*-T_\infty}{T_w^*-T_\infty^*},\quad \phi=\frac{C^*-C_\infty}{C_w^*-C_\infty^*},\quad Nr=\frac{16\sigma^* T_\infty^3}{3k^* k},$$

$$Gm=\frac{vg\beta^*(C_w^*-C_\infty^*)}{U_0^2},\quad R=\frac{R^* v(C_w^*-C_\infty^*)}{\rho c_p(T_w^*-T_\infty^*)U_0^2},\quad k_r^2=\frac{k_r^{*2} v}{U_0^2},\quad Q=\frac{\overline{Q} v}{\rho c_p U_0^2} \tag{11}$$

On introducing equation (11) into equations (2), (4) & (9), the governing equations of the problem in non-dimensional form are

$$\frac{\partial u}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+Gr\theta+Gm\phi-\left(M+\frac{1}{k}\right)u \tag{12}$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial y}=\left(\frac{1+Nr}{\mathrm{Pr}}\right)\frac{\partial^2 \theta}{\partial y^2}+Q\frac{\partial \theta}{\partial y}+R\phi \tag{13}$$

$$\frac{\partial \phi}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2}-Kr^2\phi \tag{14}$$

The corresponding initial and boundary conditions are

Case (I): $u=u_p,\quad \theta=1+\varepsilon e^{nt},\quad C=1+\varepsilon e^{nt}\quad at\quad y=0$

$$u\to 0,\quad \theta\to 0,\quad C\to 0\quad as\quad y\to\infty \tag{15}$$

Case (II): $u=1+\varepsilon e^{nt},\quad \theta=1+\varepsilon e^{nt},\quad C=1+\varepsilon e^{nt}\quad at\quad y=0$

$$u\to 0,\quad \theta\to 0,\quad C\to 0\quad as\quad y\to\infty \tag{16}$$

SOLUTION OF THE PROBLEM

The equations (12) to (14) are coupled non-linear partial differential equations whose solution, in closed form is difficult to obtain, to solve these non-linear partial differential equations, we assumed the velocity, temperature and concentration fields as

$$\begin{aligned} u &= u_0(y) + \varepsilon e^{nt} u_1(y) + 0(\varepsilon^2) \\ \theta &= \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + 0(\varepsilon^2) \\ \phi &= \phi_0(y) + \varepsilon e^{nt} \phi_1(y) + 0(\varepsilon^2) \end{aligned} \tag{17}$$

We now substitute equation (17) in equations (12) to (14) and equating harmonic and non-harmonic terms, neglecting higher order terms in ε, we obtain:

$$u_0'' + u_0' - M_1 u_0 = -Gr\theta_0 - Gm\phi_0 \tag{18}$$

$$u_1'' + u_1' - (n + M_1)u_1 = -Au_0' - Gr\theta_1 - Gm\phi_1 \tag{19}$$

$$\theta_0'' + h(1+Q)\theta_0' = -Rh\phi_0 \tag{20}$$

$$\theta_1'' + h(1+Q)\theta_1' - nh\theta_1 = -hA\theta_0' - Rh\phi_1 \tag{21}$$

$$\phi_0'' + Sc\phi_0' - KrSc\phi_0 = 0 \tag{22}$$

$$\phi_1'' + Sc\phi_1' - Sc(Kr + n)\phi_1 = -ScA\phi_0' \tag{23}$$

Where $M_1 = M + \frac{1}{k}$, $h = \frac{\Pr}{1 + Nr}$ and primes indicate differentiation with respect to y.

The boundary conditions are:

Case (I): $u_0 = u_p, \quad u_1 = 0, \quad \theta_0 = 1, \quad \theta_1 = 1, \quad \phi_0 = 1, \quad \phi_1 = 1 \quad at \quad y = 0$

$$u_0 \to 0, \quad u_1 \to 0, \quad \theta_0 \to 0, \quad \theta_1 \to 0, \quad \phi_0 \to 0, \quad \phi_1 \to 0 \quad as \quad y \to \infty \tag{24}$$

Case (II): $u_0 = 1, \quad u_1 = 1, \quad \theta_0 = 1, \quad \theta_1 = 1, \quad \phi_0 = 1, \quad \phi_1 = 1 \quad at \quad y = 0$

$$u_0 \to 0, \quad u_1 \to 0, \quad \theta_0 \to 0, \quad \theta_1 \to 0, \quad \phi_0 \to 0, \quad \phi_1 \to 0 \quad as \quad y \to \infty \tag{25}$$

The solutions of (18) to (23) under the transformed boundary conditions (24) and (25) yield

$$\phi_0 = e^{-m_1 y} \tag{26}$$

$$\phi_1 = B_1 e^{-m_1 y} + B_2 e^{-m_2 y} \tag{27}$$

$$\theta_0 = B_3 e^{-m_1 y} + (1 - B_3) e^{-m_3 y} \tag{28}$$

$$\theta_1 = B_4 e^{-m_1 y} + B_5 e^{-m_1 y} + B_6 e^{-m_3 y} + B_7 e^{-m_4 y} \tag{29}$$

$$u_0 = B_8 e^{-m_1 y} + B_9 e^{-m_3 y} + B_{10} e^{-m_5 y} \tag{30}$$

$$u_1 = B_{11} e^{-m_1 y} + B_{12} e^{-m_2 y} + B_{13} e^{-m_3 y} + B_{14} e^{-m_4 y} + B_{15} e^{-m_5 y} + B_{16} e^{-m_6 y} \tag{31}$$

Skin Friction

The skin-friction coefficient at the plate is given by

$$\tau = \left[\tau_{xy} / \rho v_0^2\right]_{y=0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{32}$$

Nusselt Number

Rate of heat transfer in terms of Nusselt number, at the plate is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} \tag{33}$$

Sherwood Number

Rate of mass transfer in terms of Sherwood number at the plate is given by

$$Sh = \left(\frac{\partial \phi}{\partial y}\right)_{y=0} \tag{34}$$

RESULTS AND DISCUSSIONS

The non-dimensional boundary layer governing equations for velocity flow, energy and concentrations with corresponding boundary conditions have been solved by perturbation method. In the present study, following default parameter values are adopted for computations u_p= 0.5, Sc = 0.78, t = 1, n = 0.5, Kr = 0.5, A = 0.5, ε = 0.02, Nr = 0.1, Q = 0.1, R = 0.1, M = 0.5, k = 1, GM = 5, Gr = 10. All graphs therefore, correspond to these values unless specifically indicated on the appropriate graph.

Case (I): The fluid velocity variation in case of externally cooled plate is shown in figure 1 for various values of Schmidt number Sc. It is observed that, for heavier diffusing foreign species, i.e., increasing the Schmidt number leads to a decrease in the velocity. Figure 2, shows the effect of magnetic parameter M, on the velocity profiles. The velocity profiles decrease with the increase in M. When M increases, this will also increase the Lorentz force, which opposes the flow and leads to enhanced deceleration of the velocity profiles. The influence of the radiation absorption parameter R, on the velocity and temperature profiles is shown in figures 3 and 4, respectively. It is obvious that, an increase in the radiation absorption parameter results in increasing velocity and temperature, within the boundary layer.

Case (II): Figure 5, shows that, the velocity profiles for different values of heat source parameter Q. The

numerical results show that, the effect of increasing values of heat source parameter Q, results in a decreasing velocity. The influence of the radiation parameter Nr of the velocity and the temperature profiles are shown in figures 6 and 7, respectively.

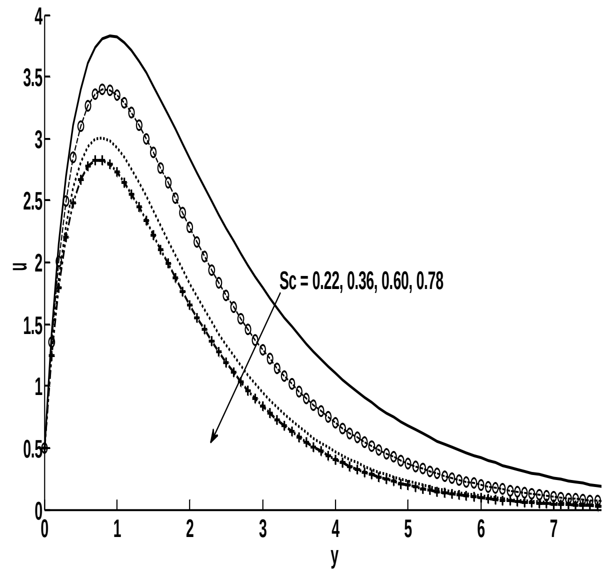

Figure 2: Effect of Sc on Velocity Field

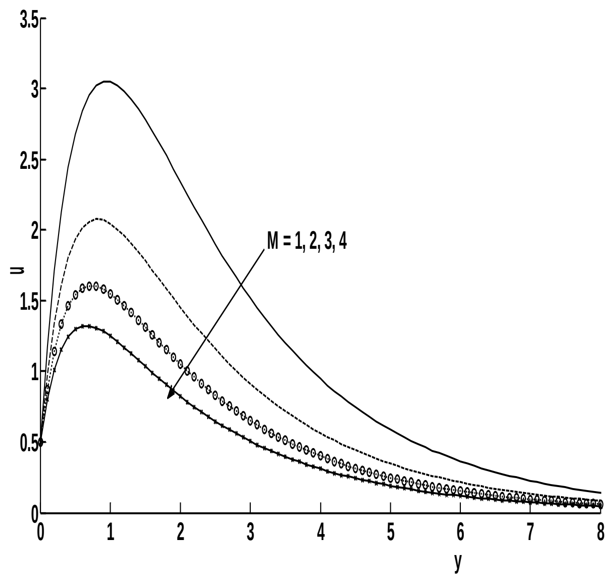

Figure 3: Effect of M on Velocity Field

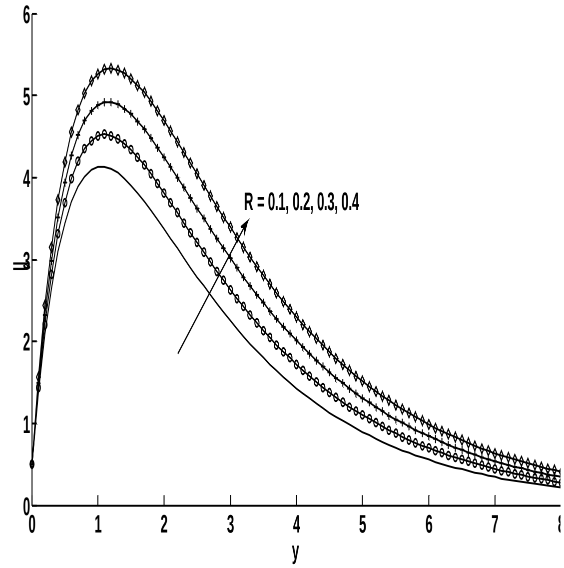

Figure 4: Effect of R on Velocity Field

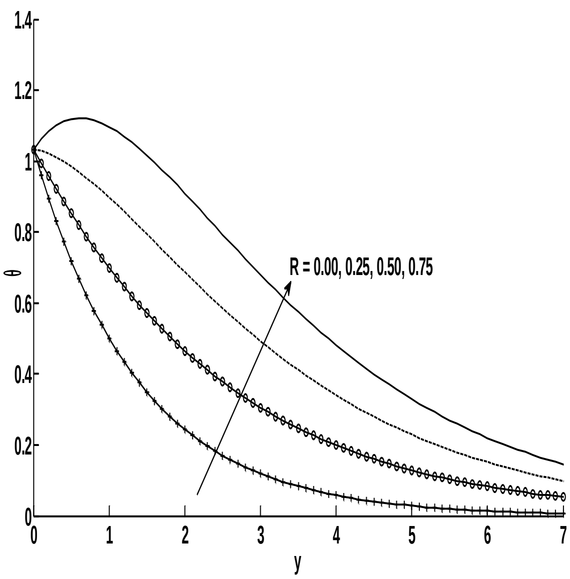

Figure 5: Effect of R on Temperature Field

The radiation parameter Nr, defines the relative contribution of conduction heat transfer to thermal radiation transfer. It is obvious that, an increase in the radiation parameter results in increasing velocity and decreasing the temperature. Figure 8, shows the effect of chemical reaction parameter Kr, on concentration profiles. It is observed that, an increase in chemical reaction parameter Kr decreases in concentration.

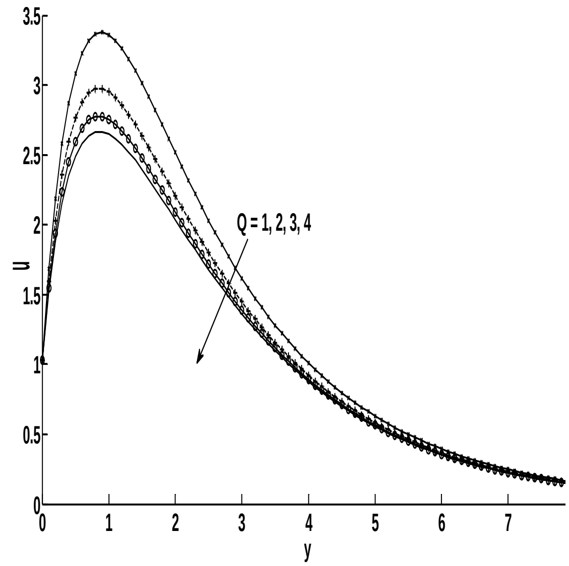

Figure 6: Effect of Q on Velocity Field

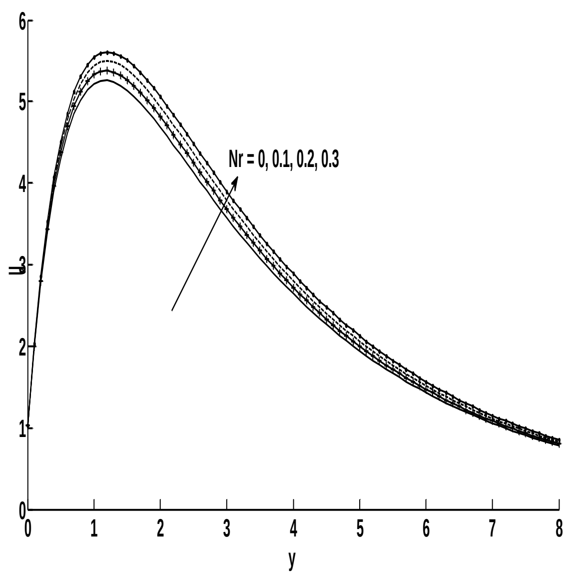

Figure 7: Effect of Nr on Velocity Field

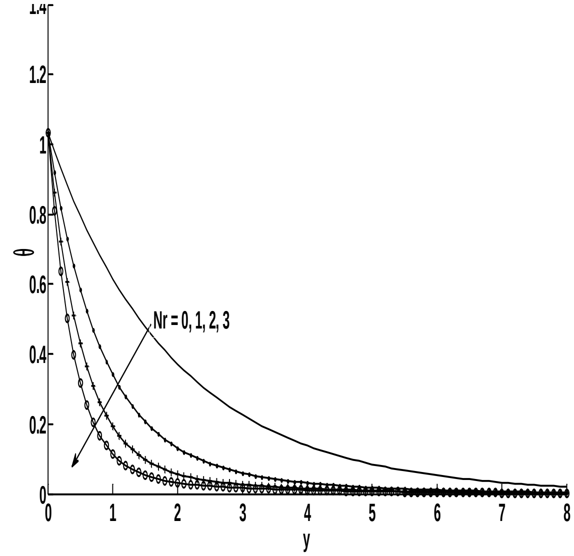

Figure 8: Effect of Nr on Temperature Field

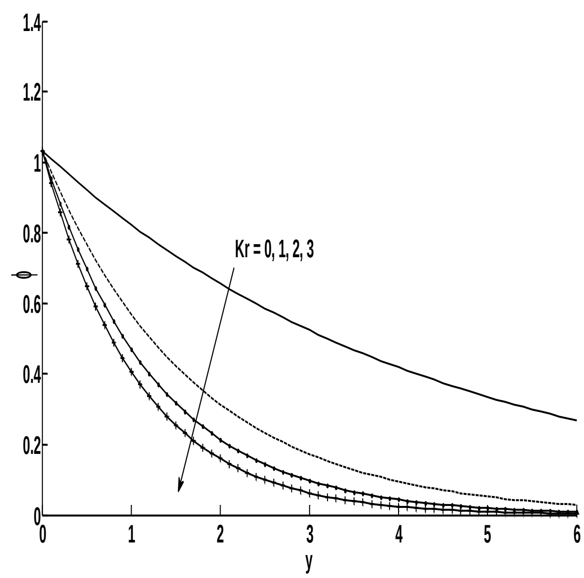

Figure 9: Effect of Kr on Concentration Field

CONCLUSIONS

The problem of the combined influence of chemical reaction and the radiation absorption effect of a magneto hydrodynamic free convective flow, embedded in a porous medium with time dependent suction and the temperature gradient heat source, has been analyzed in two different cases of boundary conditions. Graphical results for various parametric conditions were presented and discussed, for different values. The main conclusions are summarized below.

Case (I):

- The dimensionless velocity decreases with an increase in Schmidt number search.
- As the magnetic field parameter M increases, the dimensionless velocity decreases.

- With the increase in the radiation absorption, the velocity temperature increase.

Case (II):

- The dimensionless velocity decreases with an increase in heat source parameter Q.
- Velocity increases with an increase in radiation parameter Nr.
- Temperature decreases with an increase in radiation parameter Nr.
- Concentration reduces with an increase in chemical reaction parameter Kr.

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